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Physical characteristics of the Tshirege Member of the Bandelier Tuff with reference to use as a building and ornamental stone

By

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Introduction

The suitability of the Tshirege Member of the Bandelier Tuff for insulation, ornament, building stone, and other uses is dependent on its availability, accessibility and physical properties. At the request of Mr. Paul Tafoya, Governor of Santa Clara Indian Pueblo and Mr. W. Williams, Advisor of the Community Action Program at Santa Clara, New Mexico, the information available as to its geographical and geological accessibility and its physical properties are presented in this report. The information will be useful in the Community Action Program for developing and enlarging the Puye Cliff Dwelling area as a tourist facility. It may also suggest other uses for the stone to anyone who may be interested.

The information contained in this report was abstracted from reports in the files of the U.S. Geological Survey, prepared for and in cooperation with the U.S. Atomic Energy Commission and the University of California's, Los Alamos Scientific Laboratory at Los Alamos, New Mexico. The reports that contain the information on the physical properties of the tuff were prepared from data collected during investigations related to the disposal of solid waste materials, industrial effluents, and studies pertaining to the development of ground-water supply at Los Alamos.

The fact that some of the tuff is suitable for building purposes was recognized by the historical cliff dwellers, and in modern times by the builders of the first houses at Los Alamos. It was found to have good insulating properties and good strength as well as beauty. It was used to construct four fireplaces at the Los Alamos Lodge. Among the newer buildings constructed of tuff are: the fire tower, these buildings of the Los Alamos Building and Loan Company, and the Gate Restaurant. Also, many stone fences, retaining walls, drainage ditches, and protective slope covers are constructed of tuff at Los Alamos. A few homes and fireplaces in Albuquerque are constructed of tuff.

Availability and accessibility

The tuff is available in large quantities and also reasonably accessible because of its favorable geographic location and geologic occurrence. It is the cap rock of a large plateau lying between the volcanic center, Sierra de los Valles, on the west and the Rio Grande on the east in North-central New Mexico (fig. 1). This tuff has

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Figure 1 (caption on next page) belongs near here.

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been sculptured by erosion into a picturesque arrangement of canyons, mesas, and cliffs roughly parallel to each other and all extending outward and downslope toward the river, away from the volcanic center to the west. This slope feature with all of its canyons and mesas is called the Pajarito Plateau (Hewitt, 1953). It was originally a nearly-smooth sloping surface formed as the result of the accumulation of hot volcanic ash material ejected from the volcanic center to the west (Valles Caldera).

Rocks exposed on or near the Pajarito Pleateau are the Tesuque Formation, Puye Conglomerate, the Tschicoma Formation, and the Bandelier Tuff. A generalized east-west geologic section showing their relationship in an area south of Santa Clara Indian Reservation is shown on figure 2. A detailed description of these formations can

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be found in Griggs (1964) and Spiegel and Baldwin (1963).

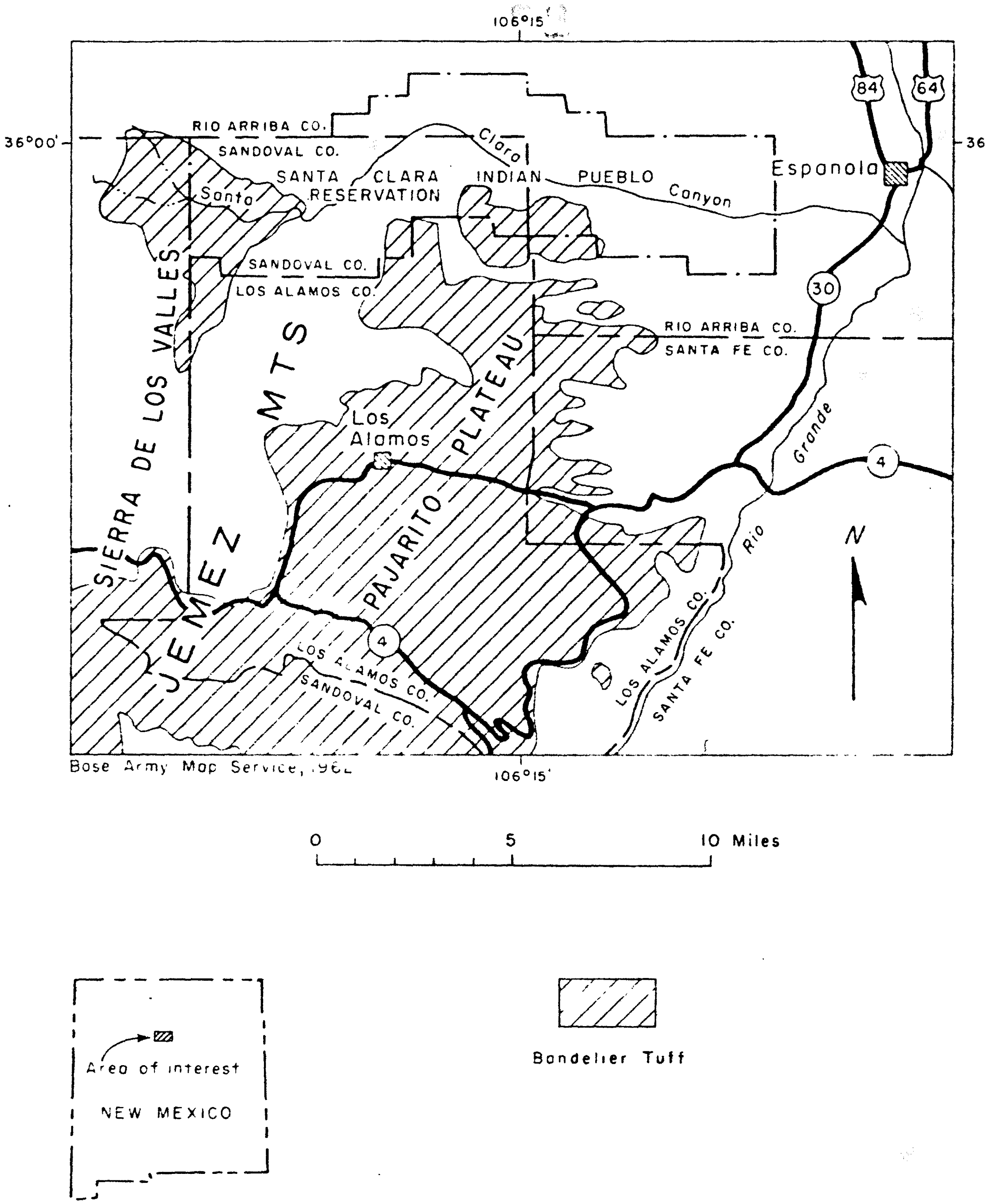

Figure 1.--Map showing topographic features in the region of the Santa Clara Indian Reservation and their relation to the Bandelier Tuff (shaded) of the Jemez Mountains.

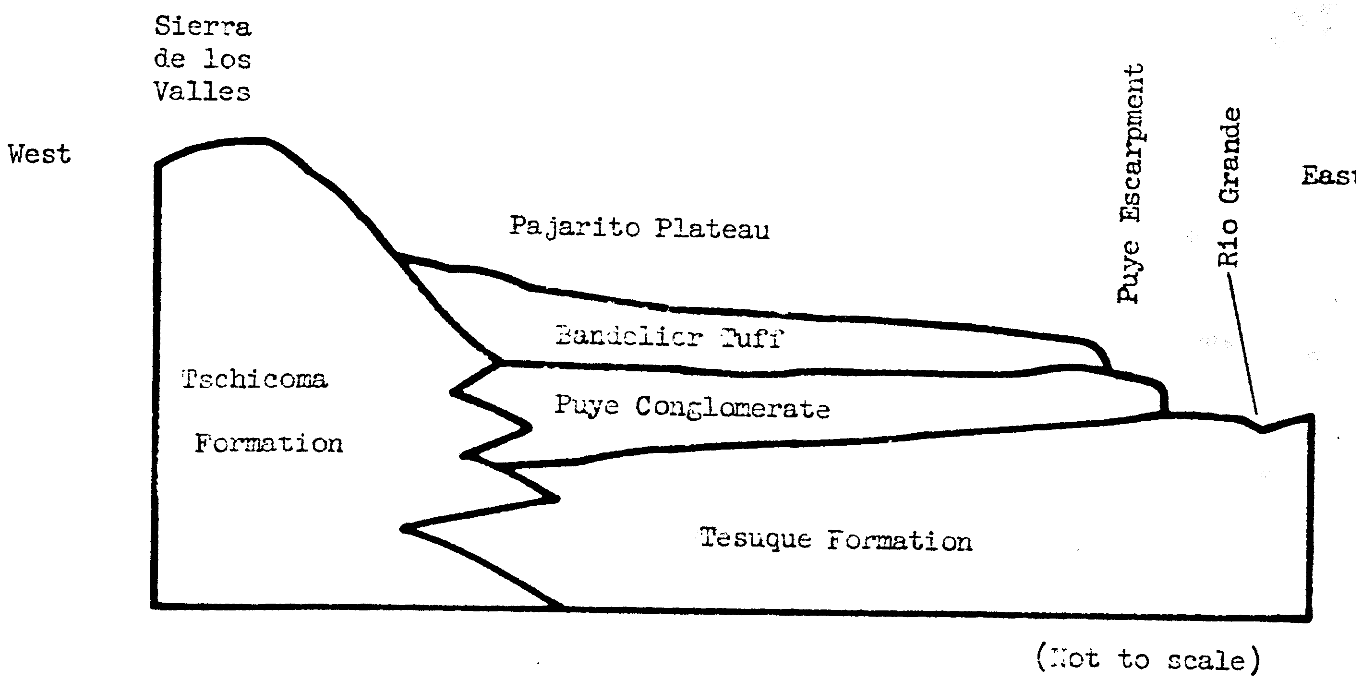

Figure 2.-- Diagrammatic cross section showing the relation of geologic formations in the area south of the Santa Clara Indian Reservation

Figure 1.--Map showing topographic features in the region of the Santa Clara Indian Reservation and their relation to the Bandelier Tuff (shaded) of the Jemez Mountains.

2.--Diagrammatic cross section showing the relation of geologic formations in the area south of the Santa Clara Indian Reservation.

The Bandelier Tuff was formed from a series of ash falls and ash flowes ejected from the volcanic center to the west. It is of rhyolitic composition and consists of three members that form a part of the Pajarito Plateau. From oldest to youngest, the members are the Guaje, Otowi, and Tshirege.

The Guaje Member consists of light-gray ash-fall pumice and water-laid pumiceous tuff. The base of the unit contains gray lumps of pumice as much as 2 inches in length. The average thickness of the Guaje ranges from 20 to 35 feet. Pumice from the Guaje Member is mined for use in concrete aggregate.

The Otowi Member consists of a light-gray, nonwelded, friable, pumiceous, rhyolite tuff that weathers to a gentle slope. Its thickness varies and may be as much as 400 feet beneath the central part of the plateau. The nonwelded friable unit would not be suitable as a building stone.

The Tshirege Member overlies the Otowi Member and it forms the cap rock of the finger-like mesas of the Pajarito Plateau. It was formed of a series of ash flows nonwelded into a series of rhyolite tuff. Because of its physical properties, described in the following section, some layers of the tuff are well suited to use as building and ornamental stone. A detailed description of the Tshirege Member is given in the following section.

The Tshirege Member is well exposed along the canyon walls and is also readily accessible under a thin mantle of surface soil on the mesa tops.

Physical characteristics of the Tshirege Member of the Bandelier Tuff

The tuffs of the Tshirege Member were formed by a series of ash flows and ash falls which are described as nonwelded, moderately welded, and welded tuff. The nonwelded, moderately welded, and welded tuff grade one into the other both vertically and horizontally.

Welding

The welding process of an ash-flow tuff begins after emplacement. The major factors affecting welding are heat at the time of emplacement, amount of volatiles in the mass, rate of cooling, and thickness of the ash flow. The degree of welding ranges from incipient stages marked by the sticking together or cohesion of glassy fragments to complete welding marked by the cohesion of the surfaces of glassy fragments accompanied by their deformation and elimination of pore space (Smith, 1960).

Zonal variation of welding occurs vertically within individual flows or within a series of flows that have cooled as a single unit. Single ash flows that have cooled as a unit may show a greater degree of welding near the center than near the upper and lower contacts. A series of ash flows that have been emplaced in rapid succession may cool as a single unit with the greatest degree of welding near the center.

Variation of welding occurs horizontally within individual flows with greater degree welding near the mountains (the source area). The degree of welding becomes less eastward across the plateau.

The tuffs in the Los Alamos area are classified according to the degree of welding--i.e., nonwelded, moderately welded, and welded tuffs. Welding results in increased cohesion and deformation of the glassy fragments in the tuff. Nonwelded tuff has high porosity, only slight cohesion of the glassy fragments, and crumbly fracture; moderately welded tuff has lesser porosity, moderate cohesion, slight deformation of the glassy fragments, and a somewhat brittle fracture; and welded tuff has lower porosity, good cohesion, a high degree of deformation by flattening of glassy fragments, and a brittle fracture.

The degree of welding influences most of the physical characteristics of the individual ash-flow tuff units.

The following shows a large range in porosity in each of the variations of tuff indicating that welding is only one of several factors determining porosity.

	Range in porosity (percent by volume)
Nonwelded tuff	40 to 60
Moderately welded tuff	30 to 55
Welded tuff	15 to 40

Density

The bulk density of nonwelded tuff is lower than in welded tuff. This is due to the compaction of the matrix (glass shards and ash) and closer arrangement of the quartz and sanidine, crystals, and rock fragments in the process of welding of a welded tuff. The specific gravity of the tuff matrix averages about 2.55. The range in bulk density of nonwelded to welded tuff depends on the porosity (i.e., the larger a porosity the smaller the buld density).

The following table shows a comparison of the bulk densities of the tuff (nonwelded to welded) with other building stone.

Building stone	Range in bulk density (lbs. in cu. ft.)
Nonwelded tuff	64- 95
Moderately welded tuff	72-115
Welded tuff	95-135
Brick[1/]	87-137
Granite[1/]	165-172
Marble[1/]	160-177
Sandstone[1/]	134-147
Concrete[1/]	170-190

1/ Handbook of Physics and Chemistry, 1958.

Bearing capacities

The bearing capacities of a tuff are dependent upon the density of tuff (i.e., the greater bearing capacities occur with the tuff of greater density). The density of the tuff is related to welding (i.e., density of the tuff increases from nonwelded tuff to welded tuff).

Data are available on the bearing capacities of the moderately welded tuff. The following table shows the relationship of density change to the resistance to crushing of a moderately welded tuff in the area of investigation.

Bulk density (lbs. per cu. ft.)	Resistance to crushing (lbs. per sq. ft.)
108	48,800
109	73,000
111	79,200
112 (probably with pumice inclusion)	69,200
113	99,200
114	115,600

Pumice fragment inclusion in a small sample of the tuff would decrease the bearing capacity as failure would most likely occur within the pumice fragment.

The following table is a comparison of the bearing capacities of a moderately welded tuff (density 108 and 114 lbs. per cu. ft.) and miscellaneous building stone. The bearing capacity is computed as 1/5 of rupture strength of the material.

Building stone	Bearing capacity (lbs. per sq. ft.)
Moderately welded tuff (108 lbs. per cu. ft.)	9,700
Moderately welded tuff (114 lbs. per cu. ft.)	23,000
Concrete 1/	23,000
Sandstone 1/	69,000
Brick 1/	86,000
Marble 1/	219,000
Granite 1/	279,000

1/ Handbook of Chemistry and Physics, 1958.

The moderately welded tuff is a good structural building stone as its bearing capacity is roughly comparable to concrete with a density or weight of about half that of concrete.

Thermal conductivity

The thermal conductivity of the tuff is related to porosity, thus, the thermal conductivity of a nonwelded tuff would be less than a welded tuff as more pore space is available for insulation.

The only data available on the thermal conductivity was made of a moderately welded tuff in one area investigated. The following table is a companion of the thermal properties of the tuff and miscellaneous building stone. A decrease in thermal conductivity increases the insulating value.

Building stone or material	Range of thermal conductivity (B.T.U. per hr. per sq. ft. and temp. gradient of 1°F per in. thickness)
Rock wool 1/	0.26- 0.29
Moderately welded tuff	.31- .38
Brick 1/	3 - 6
Concrete (set) 1/	6 - 9
Sandstone 1/	8 -16
Marble 1/	14 -20
Granite 1/	13 -28

1/ Handbook of Chemistry and Physics, 1958.

The moderately welded tuff is a better insulation than other building materials. A building constructed of a moderately welded tuff may not need additional insulation.

Chemical composition

The chemical composition of a rock may affect its usefulness in a concrete aggregate and for other purposes. The following table shows a representative analyses of the tuff.

Chemical constituents	Range in percent
Silica (SiO_2)	72.0 -78.2
Alumina (Al_2O_3)	11.2 -13.8
Ferric oxide (Fe_2O_3)	1.1 - 2.1
Ferrous oxide (FeO)	.21- .75
Magnesium oxide (MgO)	.02- .33
Calcium oxide (CaO)	.26- 1.17
Sodium oxide (Na_2O)	3.5 - 4.5
Potassium oxide (K_2O)	4.2 - 4.7
Water (H_2O)	.15- 2.8
Titanium oxide (TiO_2)	.10- .32
Phosphorous oxide (P_2O_5)	.10- .07
Manganese oxide (MnO)	.00- .98
Carbon dioxide (CO_2)	$<$ .05

Mineral composition

The tuff is rhyolitic in composition and contains small rock fragments of rhyolite, latite and devitrified pumice and crystals and crystal fragments of sanidine, and quartz, in a matrix of glass shards and welded ash. Dark minerals are scarce although traces of crystal fragments of biotite, hornblende, and pyroxene have been observed (Griggs, 1964).

Seven samples of a moderately welded tuff were analyzed petrographically by C. S. Ross (written communication, July 7, 1960). Ross recalculated the proportions of phenocrysts in terms of proportion by weight. The results of all seven were similar, one of which is presented here:

Pore space	about 30 percent by volume
Phenocrysts	about 20 percent by weight
Sanidine	12 percent by weight
Quartz	6 percent by weight
Magnetite	1± percent by weight
Pyroxene	0.5± percent by weight

The ground mass is typical devitrified welded tuff. The devitrification products are very fine-grained, but show typical cristobalite-feldspar structure. Cavities contain radial groups of feldspar and tridymite. The rocks contain a few areas of altered andesite, and some brown birefracting clay like material (probably montmorillonite).

Pumice, rhyolite, and latite rock inclusions

Rock inclusions of pumice, rhyolite, and latite are found in the tuff. The frequency of occurrence of the rock fragments differs in individual ash flows and at different locations within the same ash flow.

The pumice fragments may be as much as two inches in length and one inch in diameter. The pumice is soft and friable and should cause no problem in cutting the tuff. The rhyolite and latite fragments are dark gray, hard, and may be as much as two or three inches across. These large rock fragments may cause some difficulty in cutting the tuff so that care should be taken in selecting tuff units that are void of these larger rock fragments.

Weathering and erosion characteristics

The surface of exposed tuff (nonwelded to welded) becomes "case hardened" as it is exposed to the weather. In this process, due to the porosity of the tuff, moisture is absorbed and some minerals are dissolved. The minerals are returned to the surface by evaporation as the tuff dries out where they are precipitated to form a rind. This rind forms a protective surface which resists the wearing away of the surface by wind and water. However, exposed pumice fragments weather out rapidly to enhance the beauty of the stone.

Lichens grow on tuff where moisture accumulates for brief periods. Lichens covered tuff has been used as ornamental stone for the construction of fences and walls of houses in Albuquerque, New Mexico.

The weathering characteristics of the tuff do not affect its use as a building stone; but on the contrary, it enhances the beauty of the stone.

Color

The color of the tuff ranges from very light gray to medium dark gray. Some units range from pinkish gray to light pink. Large fragments of pumice that appear much darker than the matrix in some units enhance the color of the tuff. Moderately welded units are generally lighter in color than the welded units. The coloring is inherent in the tuff and probably the result of minor changes in the chemical constituents and heat of emplacement. Weathering of the tuff changes the color very slightly.

Natural moisture content

The natural moisture content of the tuff forming the mesas between the eastward-trending canyons is generally less than five percent by volume. The low moisture content of the tuff is caused by the protective cap of clayey soil derived by weathering of the tuff near the surface. The soil is thickest near the axis of the mesas and thins toward the edges where the tuff is exposed. Precipitation that is not removed by surface drainage on the mesa tops infiltrates into the soil; however, the downward movement of this water is impeded or stopped by a dense transition zone between the soil and tuff and the water is returned to the atmosphere by evapotranspiration (Abrahams, Weir, and Purtymun, 1961).

The low natural moisture content of the tuff decreases the weight of the cut stone for handling and transportation, and should aid in quarrying and cutting.

Thickness

The Tshirege Member, consisting of a series of ash-flow tuffs ranging from nonwelded to welded, is about 800 feet thick along the western edge of the Pajarito Plateau. The Tshirege thins eastward to less than 50 feet. Some of the uppermost ash flows are beveled off by erosion eastward across the plateau. Outliers of tuff overlie the Puye Conglomerate along Puye Escarpment. Most all ash flows thin eastward from the source area (Sierra de los Valles).

Nonwelded ash flows in the lower part of the Tshirege Member may be as much as 200 feet thick near the center of the plateau. Individual moderately welded and welded ash flows in the upper part of the Tshirege Member range from 20 to 120 feet thick. The thickness of these moderately welded and welded tuff units permits a large source of quarry stone.

Joints

Joints are prominent in the tuff. They divide the rocks into many irregular blocks, many of which are prismatic or columnar. The joint density in a specific area will differ with different degrees of welding. The number of joints decreases with a decrease degree of welding (fewer joints are found in nonwelded tuff than in welded tuff). The numerically predominant joints are near vertical and are persistent in length and pass through several groups of tuff units. These joints tend to curve slightly. The joint face is relatively smooth and will add rustic beauty as use as a building stone. The presence of the joints should cause no difficulty in cutting the tuff, but aid in quarrying blocks of tuff.

Conclusions

Although no studies of Tshirege Member of the Bandelier Tuff were made to determine its suitability as a foundation rock, structural building stone, ornamental stone, or as an insulating material, the information obtained in earlier studies as to its availability, accessibility, and physical properties indicates that it is well suited to those and other uses. Furthermore, it has already been used for those and other purposes, and it promises to be a valuable resource to the Santa Clara Pueblo Indians and to other citizens of New Mexico.

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